ESTIMATING EMD COST GROWTH USING LOGISTIC AND MULTIPLE REGRESSION

Presented by
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Overview

- Cost Growth in DoD Acquisitions
- Area of Study
- Methodology
- Results/Applications
- Conclusions/Recommendations
- Future Areas of Research

Identifying the Problem

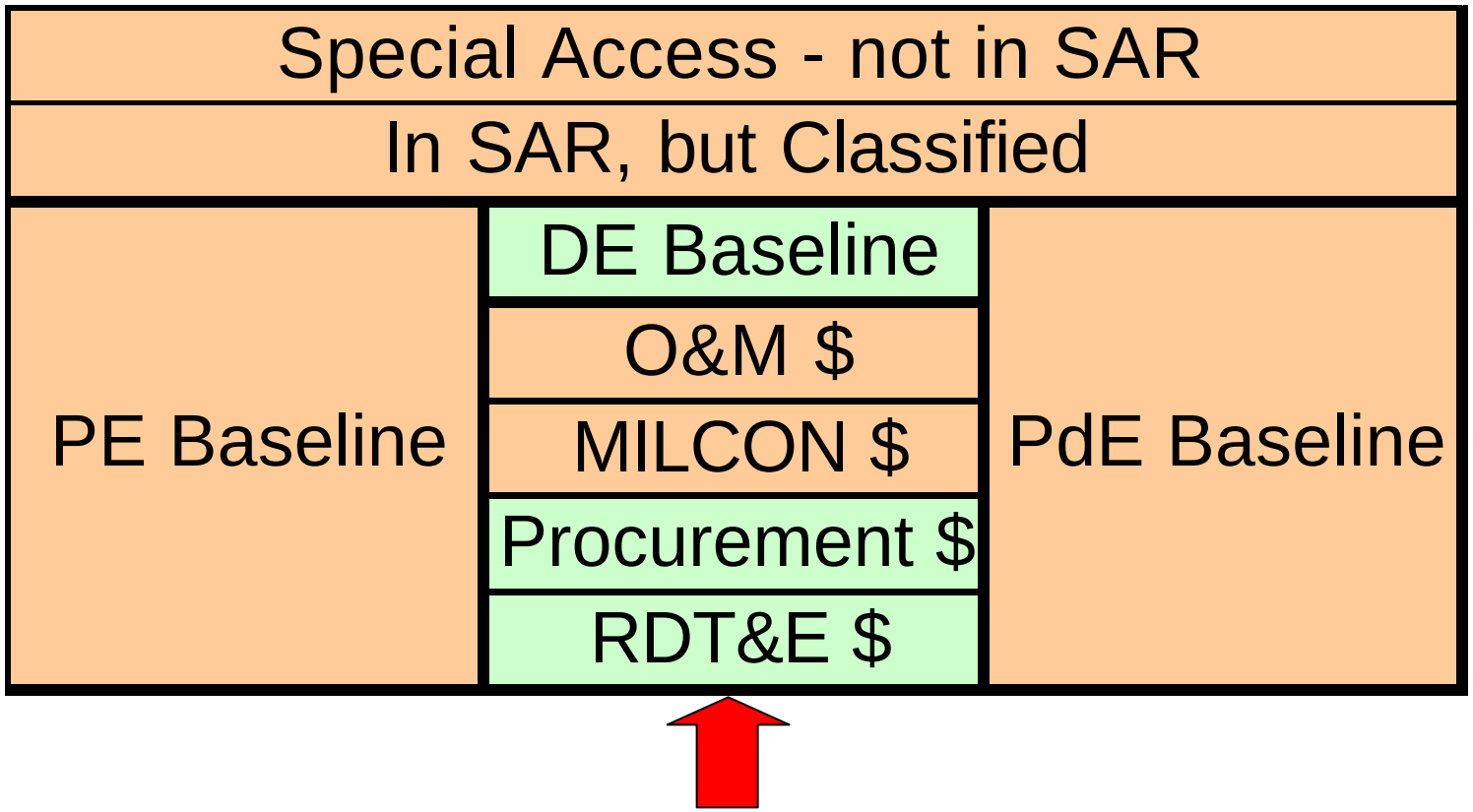
"Cost growth in major weapon systems has been an enduring problem to the Department of Defense for the last three decades" (Calcutt, 1993:1)

Solving the Problem

- Realistic Cost Estimates
  - **Research Objectives**
    - Find a statistically sound methodology that accurately predicts programmatic cost growth
    - Develop a cost-estimating relationship (CER) for the cost estimating community that accurately predicts cost growth in major acquisition programs

Area of Study

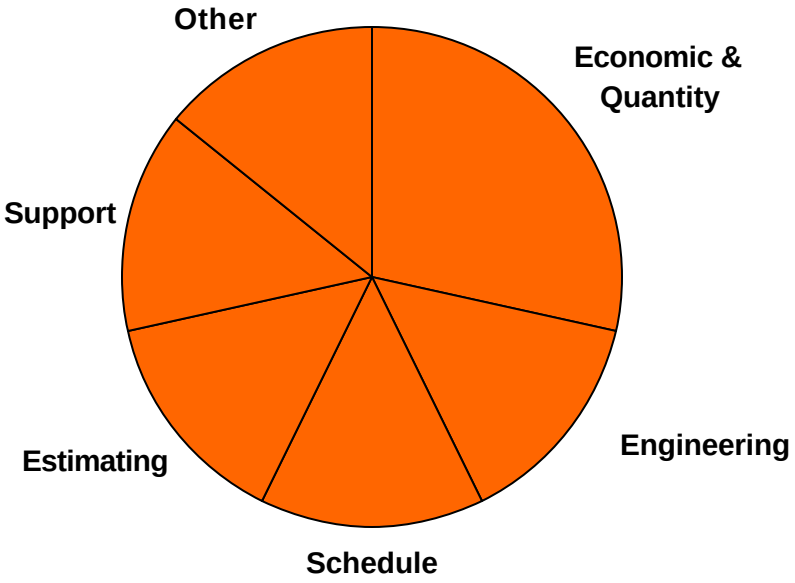
1990-2001 SAR's with DE baseline



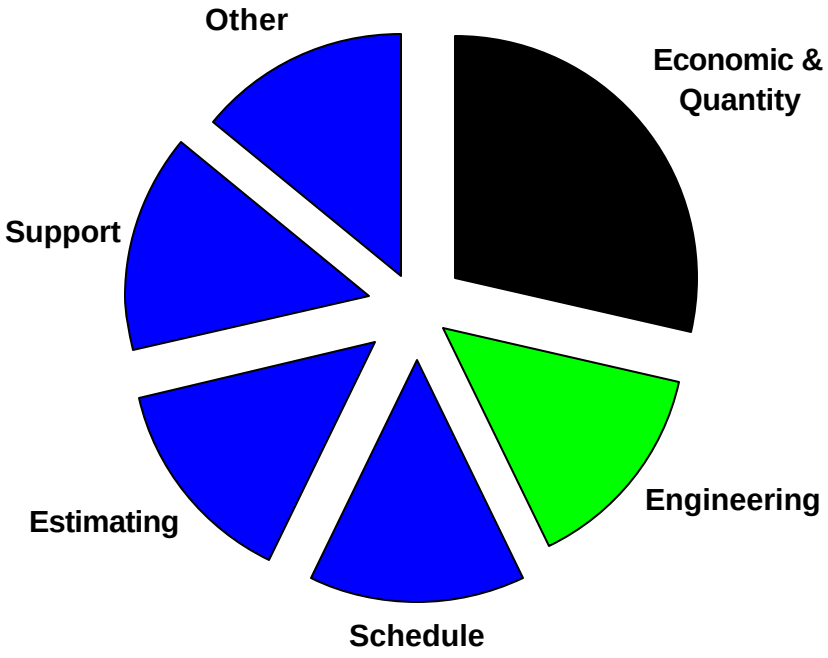
Area of Study

7 Cost Growth Categories in SAR

Procurement Dollars



RDT&E Dollars

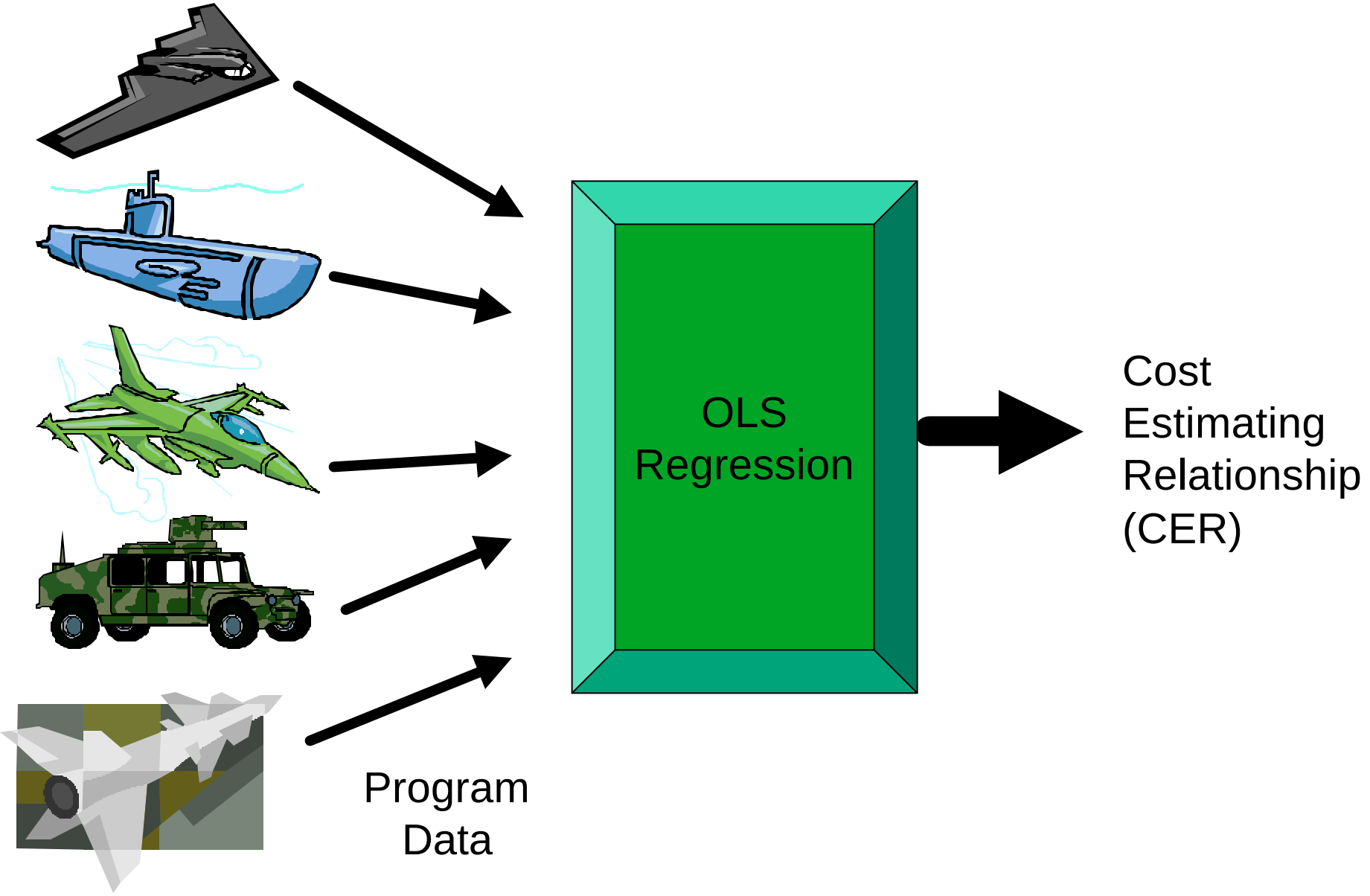


Moore Bielecki Sipple

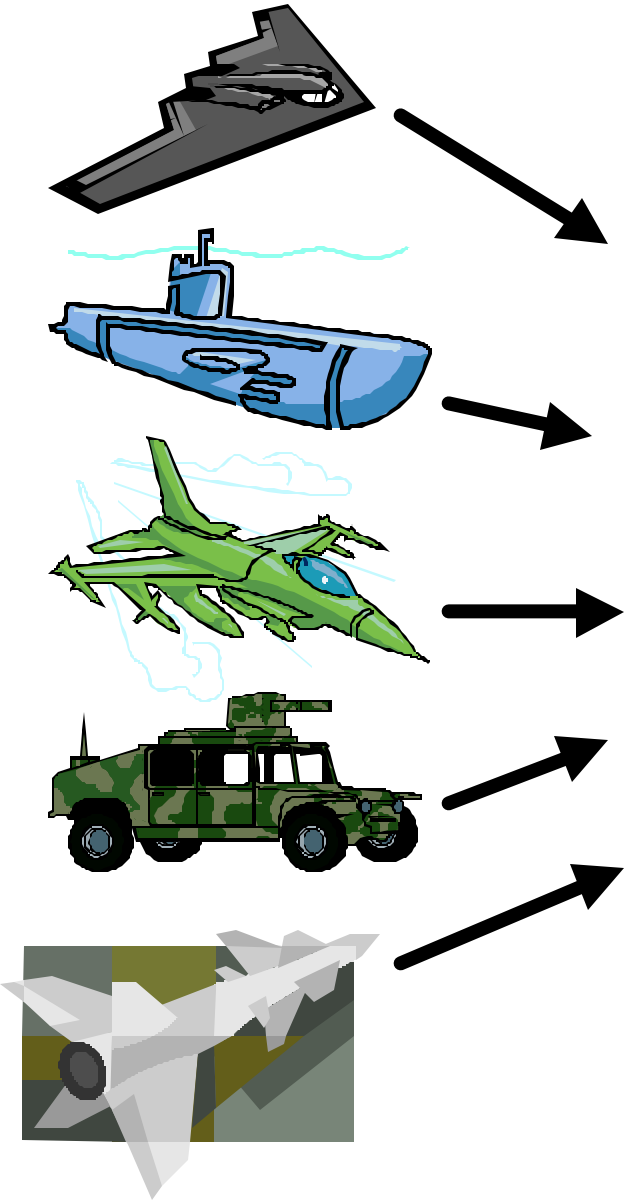
Methodology Comparison

- Single-Step Methodology
  - Ordinary Least Squares (OLS) regression
- Two-Step Methodology
  - Logistic and OLS regression
- Which is better?

Traditional Methodology



Two-Step Methodology



Cost Growth Yes/No?

If “Yes” then how much?

Logistic Regression

OLS Regression*

CER

* log transformed

Why Two Step?

- Cost growth originates from a mixture distribution
- Underlying assumption of OLS regression is a continuous response variable
- Analysis of cost growth using only OLS regression violates continuous assumption. Thus, additional step of **logistic regression** is required to satisfy underlying statistical assumption

Mixture Distribution

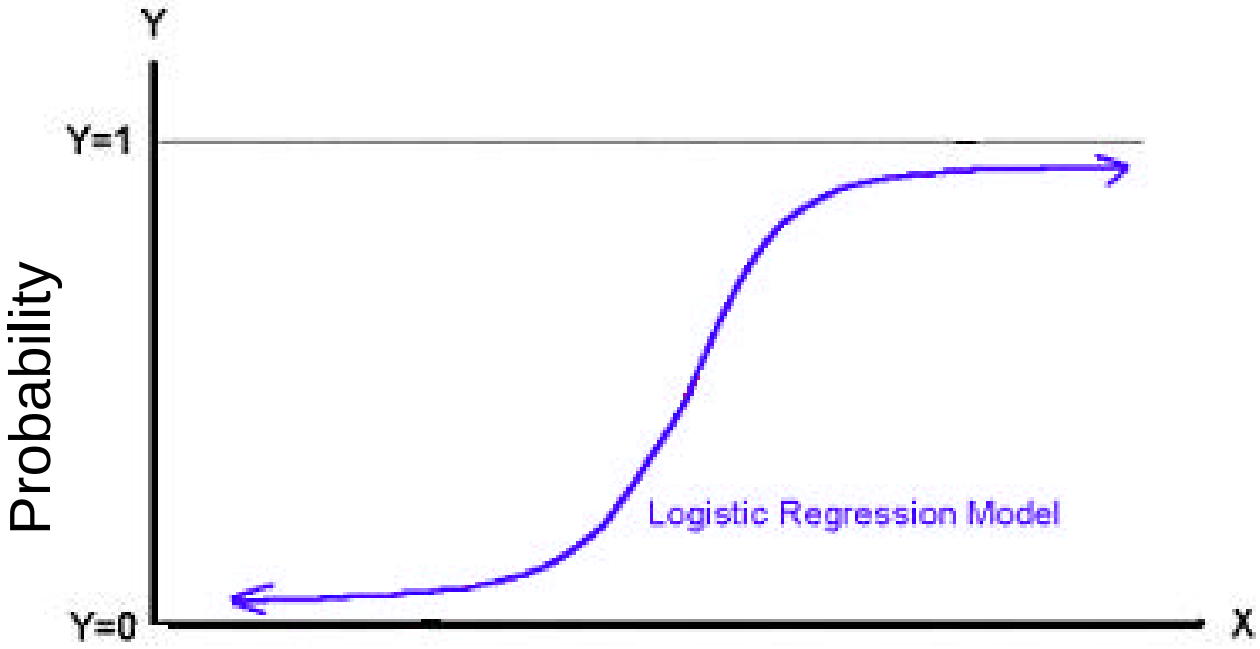
Stem	Leaf	Count
7		
6	5	1
6		
5		
5		
4		
4		
3		
3		
2	7	1
2	11	2
1		
1	001111234	9
0	5566999	7
0	1111122223444	13
-0	11100000000000000000000000000000000000000000000000000000000000	60
-0	98	2

- Stem Values are listed in tenths (.1)
- Leaf Values are listed in hundredths (.01)
- We found similar results in all areas studied

Step 1. Logistic Regression

- What is logistic regression?
  - Binary outcomes – Binomial Distribution
  - C*ost Growth?,* 1=Yes, 0=No
  - U*ses probabilities based on counts from historical database to formulate an equation*

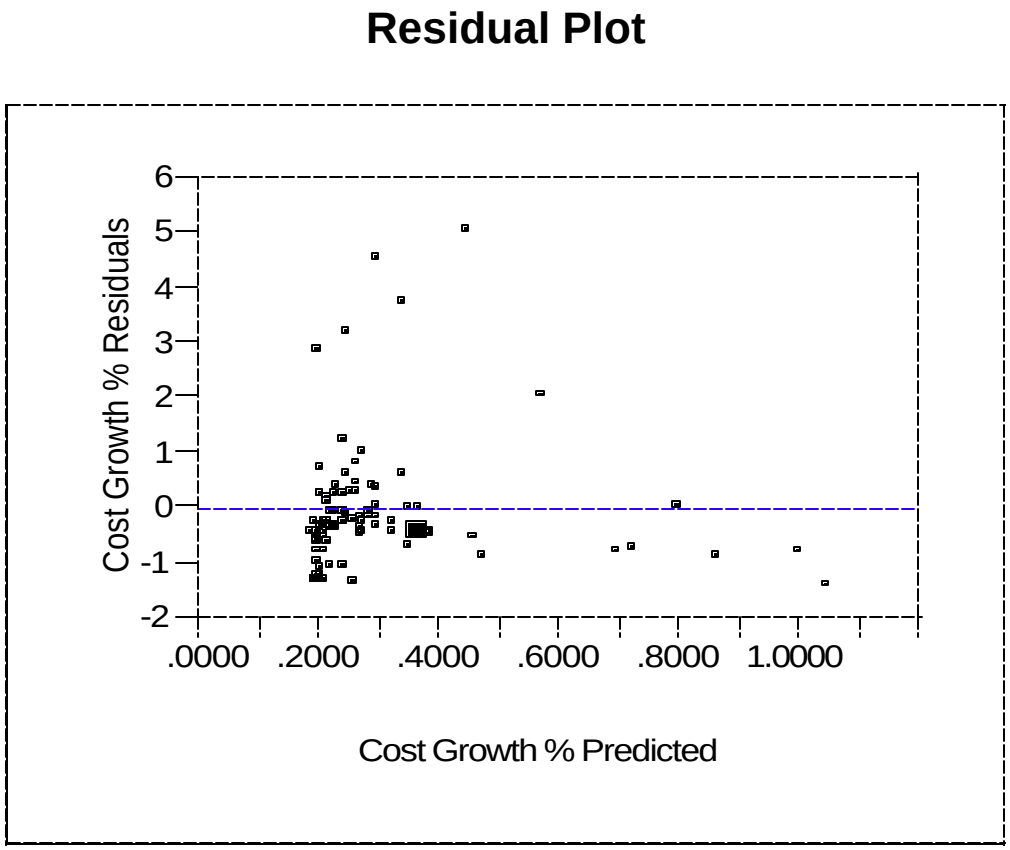
Logistic Regression



Step 2. OLS Regression

- **OLS Regression**
  - An underlying assumption of OLS regression is that the resulting residual plots pass inspection for constant variance
  - Performed preliminary test regressions and found the following…

Residual Plots

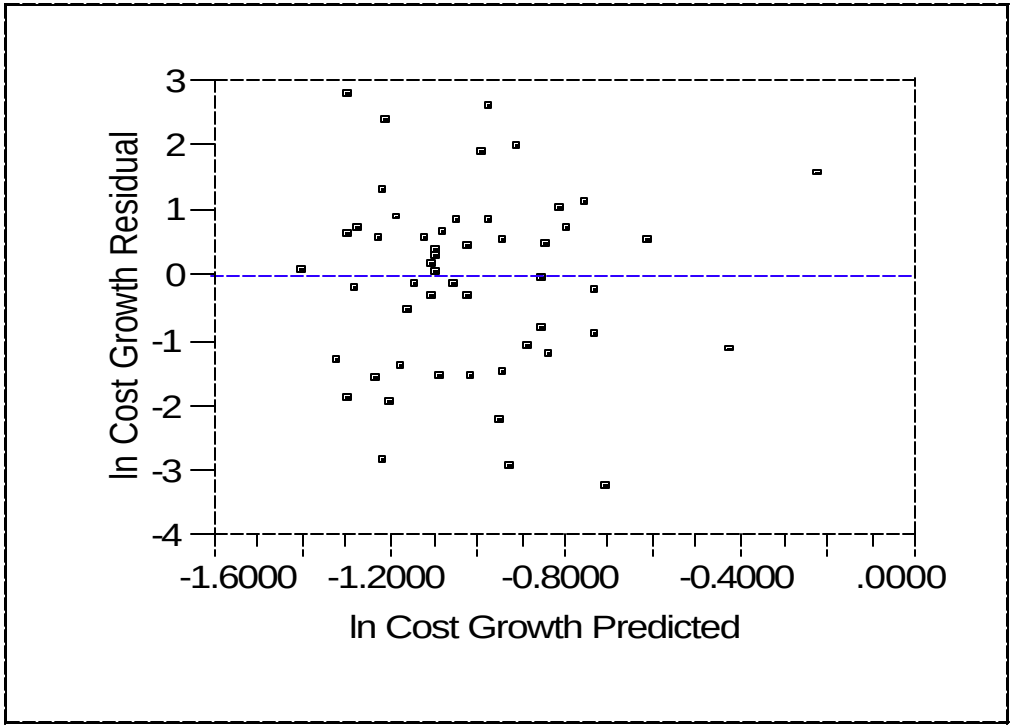


Test Regression Results:

Residuals **Do not pass** visual inspection or Breusch Pagan Test (alpha of 0.05) for constant variance

Response Variable Transformation

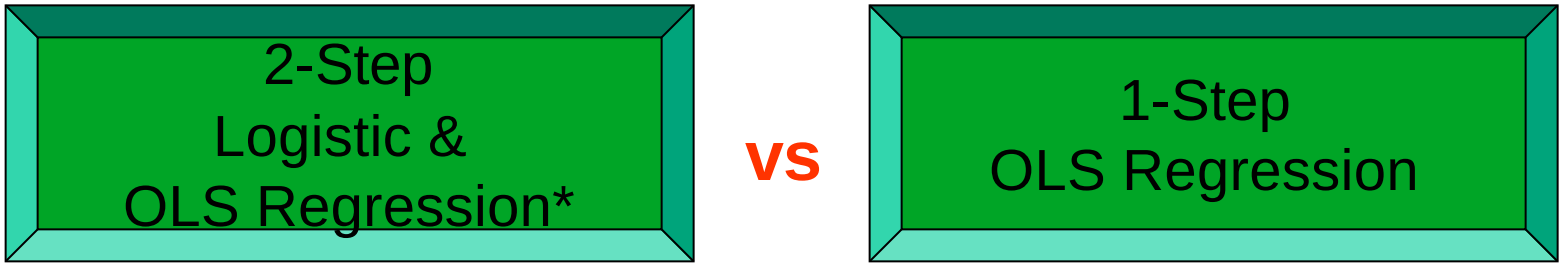
Residual Plot



Natural Log transformation corrects issues related to constant variance of residuals

We found similar results in all areas studied!

Benefits of Two-Step



- Both methods produce equivalent predictive capability
- All statistical assumptions for inferential validity met
- Result – strong statistical foundation from which to base program analysis

* log transformed

Procurement ($) Findings

- SAR database (122 data points)
  - 97 used for model building (80%)
  - 25 used for validation (20%)
- Implemented two-step methodology
- Results…

Logistic Model

Variables

Length of Production in Funding Years

***FUE-based Maturity of EMD**

Classification (U,C,S,TS)

Output

Predicts the program's probability of incurring cost growth.

Validation of Logistic Model

- Validation Data
  - 20% of original data set aside for validation
  - Success Rate = **100%** for validation data
  - Not enough data points
- More Extensive Validation
  - Validate 100% of Data
  - 39 out of 122 data points contain all three variables
  - Success Rate = **94.87%** (37 of 39)
- Results further confirm the predictive ability of this model.

OLS Model

Variables

***FUE-based length of EMD**

Controlling Service (AF, Army, Navy, Marine, or Joint)

Platform Type (Aircraft, Electronic, Missile, etc..)

Interactions

FUE-based*Controlling Service

FUE-based*Platform Type

Output

Predicts the amount of cost growth a program will incur.

Validation of OLS Model

- Validation Data
  - 20% of original data set aside for validation
  - Developed an 80 percent Upper Bound
  - Success Rate = **100%** **(Actual CG = Upper Bound)**
  - Not enough data points
- More Extensive Validation
  - Validate 100% of Data
  - 25 out of 122 data points incurred cost growth & contained all variables
  - Success Rate = **100%** (25 of 25)
- Results further confirm the predictive ability of this model.

Conclusions/Recommendations

Procurement $$

- FUE-based variables significant predictor of Cost Growth
  - •FUE-based Maturity (Logistic) – The more mature a program is, the more likely it is to have incurred cost growth.
  - •FUE-based length of EMD (Multiple) – The longer the length of EMD, the greater the amount of cost growth.
- Other schedule variables did not predict cost growth with the same level of accuracy.
- We need Cost-Estimating Community's Assistance in Determining…..**Why FUE-based Variables?**

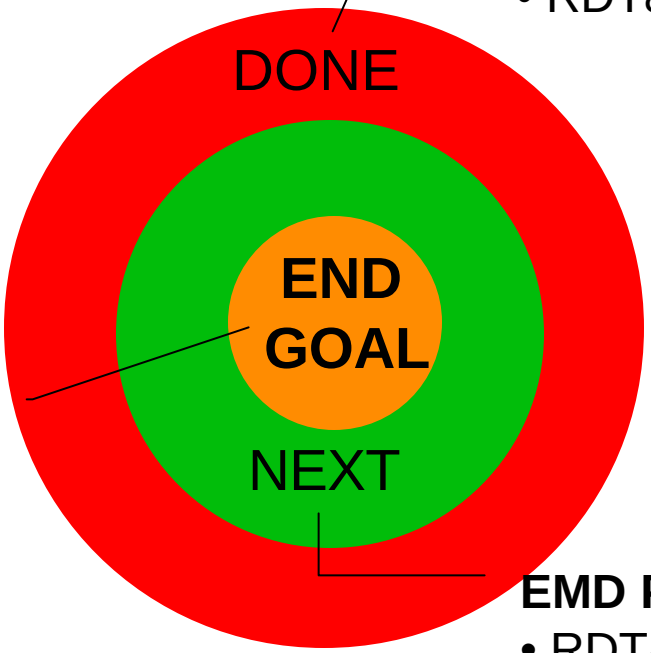
Conclusions/Recommendations

General

- Further validate the use of the two-step methodology (combining logistic and multiple regression) as a cost estimating tool
    - •Provides Analyst with Probability that a program will incur Cost Growth
    - •Removes confusing negative cost values from analysis
    - •Satisfies statistical assumptions (OLS), so models are statistically valid and provides confidence in results
- Cost Growth data originates from a lognormal distribution and requires log transformation to meet underlying assumptions of OLS regression

Future Areas of Research

More Realistic Cost Estimates



EMD Phase
- Procurement $ (Combined categories)
- RDT&E $ (Individual SAR categories)

EMD Phase
- RDT&E $ (Combined Categories)
- Total EMD (RDT&E and Procurement $)
- Link PDRR to EMD

Procurement Phase
- Untouched thus far
- Link EMD to Procurement

Contact Information

- **Primary Contacts**
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- **Other Contacts**
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- BACK UP SLIDES

Database

- 131 Programs
  - 9 Programs excluded
- 78 possible predictor variables
- Randomly selected 20% of data for validation “withhold” – the rest is for model building
- Converted to CY$ 2002

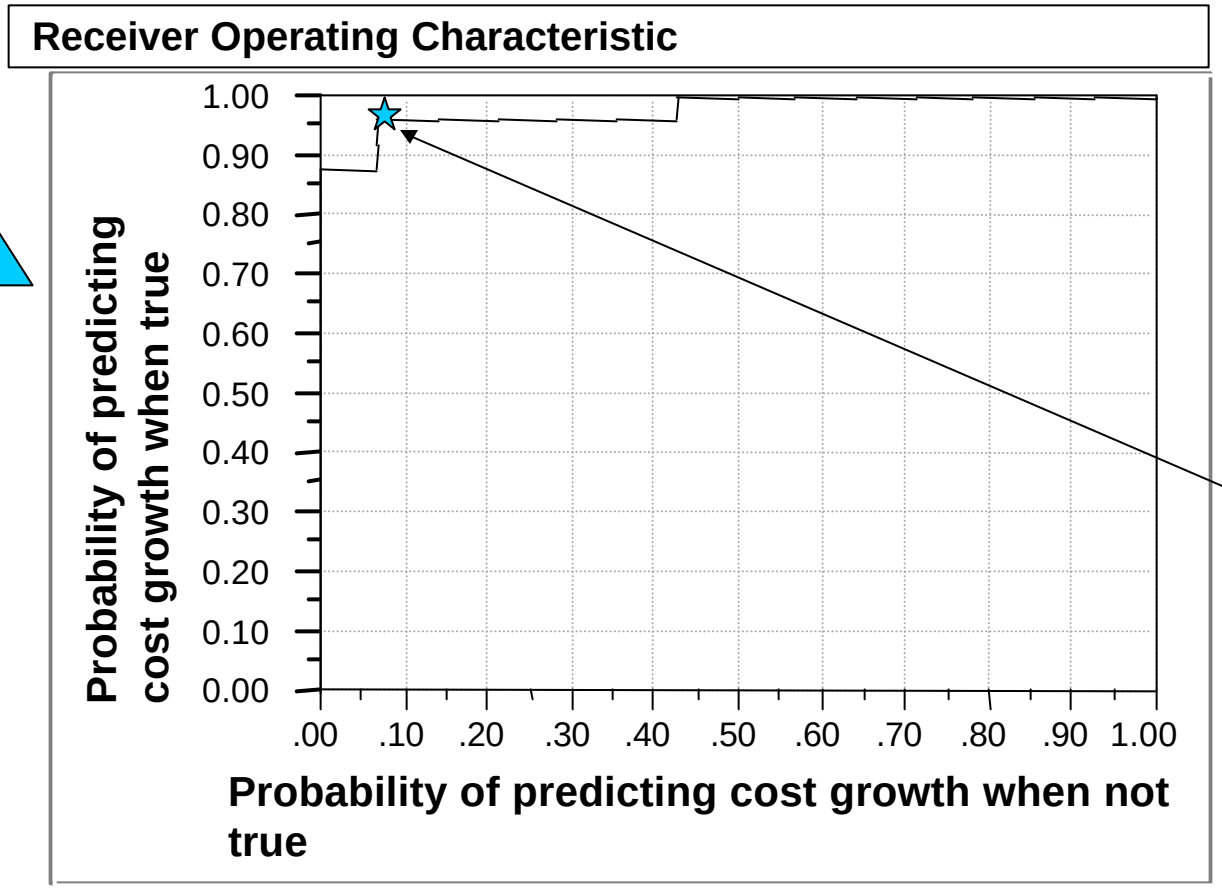
Database - Exclusions

- 6 Programs excluded for limited or no EMD effort:
  - CG 47
  - SSN 688
  - UH-60A/L
  - MCS IV
  - MCS I, II, III
  - Sensor Fuzed Weapon
- 3 programs excluded for Independence Violations:
  - AHIP Kiowa Warrior
  - Tactical Tomahawk
  - JStars CGS

Explanation of –log likelihood &“U”

- -log likelihood is the probability of obtaining a random sample identical to the observed sample under various conditions
  - “Full” refers to the likelihood using the full model
    - **Y will be a success changes as X variables change**
  - “Reduced” refers to the likelihood using only B_0
    - **Probability Y will be a success is constant**
- U = $\frac{\text{- log likelihood full – (- log likelihood reduced)}}{\text{(- log likelihood reduced)}}$

Explanation of ROC Curve



High Probability is Good

On Average: This model has approx. a 3% chance of predicting cost growth when cost growth does not occur

Low Probability is Good

Results for Procurement ($)

Evaluation Measures			
Number of Predictors	1	2	3
Uncertainty Coefficient	0.2456	0.4975	0.8307
Number of Data Points	97	35	35
Area Under ROC Curve	0.81517	0.91608	0.99301

*Whole model p-value and Lack of fit p-value were not discriminating factors between models. We consider the above measures for model comparisons.

Validation of Logistic Model

Programs	Predicted	Actual
CGS (JSTARS GSM)	0	0
CSSCS (ARMY)	1	0
E-2C Computer Upgrade	0	0
E-6A TACAMO (NAVY-COMM)	0	0
FAAD C2I	0	0
FAAD NLOS Fiber Optic Guided-Missile	0	0
IAV	0	0
Javelin (AAWS-M)	0	0
JSIPS CIGSS	0	0
MLRS Upgrade Launcher	0	0
PLS (FHTV) (ARMY)	0	0
THAAD	0	0
Tomahawk TBIP	0	0
Uh-60 Upgrade (UH-60M)	0	0

Validation of Logistic Model

Programs	Pre.	Act.
ABRAMS Tank	1	1
AFATDS	1	1
AH-64 Apache	1	1
Army TACMS	1	1
BFVS A3 Upgrade	0	1
CH-47D Chinook	1	1
CH-47F (ICH)	1	1
FMTV	1	1
Harpoon A/R/UGM-84	1	1
JSOW BLU-108	1	1
JSTARS (AIR FORCE)	1	1
Laser Hellfire	1	1
LHD-1	1	1

Programs	Pre.	Act.
Longbow Apache	1	1
Longbow Apache FCR	1	1
Longbow Hellfire	1	1
M1A2 Abrams Uprgrade	1	1
MMIII GRP	1	1
NAS	1	1
NAVSTAR User Equip	1	1
Navy Area TMBD	1	1
NSSN New Attack Sub	1	1
OH-58D	1	1
Patriot PAC-3	1	1
Titan IV (CELV)	1	1

Measures of Comparison for Multiple Regression

Evaluation Measures				
Number of Predictors	3	4	5	6
Adjusted R^2	0.594562	0.450139	0.45216	0.522666
Number of Data Points	22	51	51	51

3-Variable Model has limited data points due to **“FUE-based length of EMD”**

Validation of Multiple Model

Program	Upper Bound	CG %	Correct(=1)
AFATDS	0.29823463	0.02044542	1
BFVS A3 Upgrade	1.06506215	0.06539182	1
NSSN New Attack Sub	0.34067406	0.07603231	1
JSTARS (AIR FORCE)	0.70798088	0.13743423	1
Longbow Apache Mods	1.06506215	0.19645043	1
NAVSTAR User Equip	0.68274693	0.23135577	1
Longbow Hellfire	1.06506215	0.25796573	1
M1A2 Abrams Uprgrade	0.98674861	0.32678387	1
OH-58D Kiowa Warrior	0.43657577	0.34797855	1
Longbow Apache FCR	0.46882195	0.38306452	1
FMTV	1.62227683	0.40948964	1
Navy Area TMBD	1.5900236	0.43547886	1
Army TACMS	0.63921818	0.50230742	1
NAS	1.37714478	0.5389487	1
MMIII GRP	3.21460278	0.56099202	1
CH-47D Chinook	1.12873534	0.63318452	1
JSOW BLU-108	2.46525438	0.96972065	1
Patriot PAC-3	1.77084257	1.0265881	1
CH-47F (ICH)	1.46315307	1.19511582	1
Harpoon A/R/UGM-84	8.07029151	1.38891013	1
AH-64 Apache	1.96291705	1.44902572	1
LHD-1	2.20498034	1.48798368	1
Laser Hellfire	2.23637851	1.54969281	1
ABRAMS Tank	14.9345382	2.73540905	1
Titan IV (CELV)	18.1478484	5.56894576	1

CER Application

Logisitic Regression - RDT&E Dollars
Schedule Cost Growth

Model #2 A4

1.6936284	Input Vars	
-0.230717	15	Maturity (funding Yrs Complete)
3.6186219	0	Electronic (1=Yes, 0=No)
-0.009824	-32%	New RAND Concurrency Measure %
-3.793079	1	Service = AF only (1=Yes, 0=No)

0.996155 Probability of Cost Growth

CER Application

Logisitic Regression - RDT&E Dollars
Estimating Cost Growth

Model #1 A7

1.7323611	Input Vars	
-0.234298	10	Length of R&D in Funding Yrs
-1.768985	1	Versions pervious to SAR (1=Yes, 0=No)
2.6421238	0	N Involvement (1=Yes, 0=No)
-3.153081	0	PE ? (1=Yes, 0=No)
6.4934298	0	RAND Lead Service = DoD (1=Yes, 0=No)
1.5486272	1	Did it have a MS I ? (1=Yes, 0=No)
-1.128965	0	RAND Prototype? (1=Yes, 0=No)

0.696561 Probability of Cost Growth

CER Application

Multiple Regression - RDT&E Dollars
Schedule Cost Growth

Model #2 B4

	Input Vars	
-1.52265		
-1.495189	0	Boeing (1=Yes, 0=No)
-4.660582	0	Land Vehicle (1=Yes, 0=No)
-0.978341	0	RAND Lead Service = Navy (1=Yes, 0=No)
-0.779745	1	Did it have a MS I ? (1=Yes, 0=No)

0.100019 Estimated % Cost Growth

CER Application

Multiple Regression - RDT&E Dollars
Estimating Cost Growth

Model #1 B5

	Input Vars	
-1.147983		
0.5759717	72%	IOC - Based maturity of EMD %
-1.910945	38%	Proc Funding Yr Maturity %
-1.282748	0	General Dynamics (1=Yes, 0=No)
0.7926428	1	RAND Lead Service = Navy (1=Yes, 0=No)
-0.927261	1	PE ? (1=Yes, 0=No)

0.203099 Estimated % Cost Growth

Logistic Application (Proc $)

Logistic Formula

	Input Variables	
13.79843		
-0.8664642	22	Length of Production in Funding Yrs
-7.099219	40%	FUE-based Maturity of EMD %
-7.452441	0	Class S (1=Yes, 0=No)
0.294093	27	Length of R&D in Funding Yrs

54% Probability of Cost Growth

OLS Application (Proc $)

Multiple Formula

	Input Vars	
-0.891569		
0.0013256	112	FUE-based length of EMD
-0.098109	1	Army Only
0.0578596	8.78108781	FUE-based*Army
-0.569309	0	Electronic
0.0321444	-4.39044731	FUE-based*Electronic

0.622340 Estimated % Cost Growth